



WHY ARE HYPERONS INTERESTING AND DIFFERENT FROM NONSTRANGE BARYONS?[†]

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I. WHO NEEDS HYPERONS?

The first question to ask about any new topic is "who needs it?". One possible answer to "who needs hyperons?" is "seen one hadron, seen them all." All hadrons are alike in the zero approximation. A useful hyperon experiment must go beyond this zero approximation to observe the differences between hyperons and other hadrons. For example, a total cross section measurement for hyperon-nucleon scattering with errors too large to reveal the difference between hyperon-nucleon and nucleon-nucleon cross sections is not very useful.

The devil's advocate can assert that experiments on pions, kaons and nucleons tell how both nonstrange and strange quarks behave in hadrons and hyperon experiments will tell us nothing new. Since hyperons are made of the same quarks, their behavior can be predicted from the old data and the quark model. While tests of the various quark model predictions and sum rules are interesting, they do not give much new insight.

The one trouble with this argument is that it is wrong. Experiments on pions, kaons and nucleons don't tell us how quarks behave and we are not able to predict hyperon behavior from old data and the quark model. We still do not understand strangeness. The assertion that strange particles differ from nonstrange particles because they contain strange quarks rather than nonstrange quarks explains nothing and merely passes the buck to the quark level. Strange particles behave differently from nonstrange particles in ways which are still not understood. We do not understand the difference between kaons and pions. We need more experimental data for additional clues to understand the basic nature of strangeness and of the difference between strange and nonstrange particles.

[†]For the AIP Conference Proceedings of the 1975 Meeting of the Division of Particles & Fields held at the University of Washington, Seattle, Washington, August 26-29, 1975.



II. STRANGENESS, CHARM AND ALL THAT

The recent evidence for a new internal degree of freedom¹ such as charm brings new emphasis to our failure to understand old internal degrees of freedom like strangeness. For example, a better understanding of the production of strange particles might enable us to give better estimates for the production of charmed particles or of other exotic particles having new internal degrees of freedom. The basic open question is how strange, charmed or other exotic quarks are created on a nonstrange target.

In weak interactions the charged current has two pieces which produce strange or charmed particles in a different manner.

a. The strangeness conserving (and charm conserving) current is the dominant component and gives rise to transitions proportional to $\cos^2 \theta$ where θ is the Cabibbo angle. However these transitions can only produce strange or charmed particles in pairs on a nonstrange target.

$$J_{\text{weak}} + p \rightarrow N^* \rightarrow Y + K \quad (2.1a)$$

$$J_{\text{weak}} + p \rightarrow N^* \rightarrow \text{charmed pair} \quad (2.1b)$$

where N^* denotes some excited state of the three-quark system produced by the absorption of the energy and momentum by the target proton from the weak current.

b. The strangeness violating (and charm violating) current gives rise to transitions suppressed by the factor $\sin^2 \theta$ but can produce strange or charmed particles singly by converting a non-strange quark into a strange or charmed quark.

$$J_{\text{weak}} + p \rightarrow Y^* \rightarrow \text{strange hadron state} \quad (2.2a)$$

$$J_{\text{weak}} + p \rightarrow C^* \rightarrow \text{charmed hadron state} \quad (2.2b)$$

where Y^* and C^* denote a highly excited three-quark states in which one of the quarks is strange or charmed respectively and the final multiparticle state has a nonzero value for strangeness or charm.

The strangeness and charm conserving reactions (2.1a) and (2.1b) are produced by a stronger component of the weak current but have a higher threshold than the single production reactions (2.2a) and (2.2b) which are suppressed by the factor $\sin^2 \theta$. There is also an unknown suppression factor in the reactions (2.1a) and (2.1b) for the decay of the highly excited nonstrange system into strange or charmed pairs.

One of the unresolved problems in strangeness physics is the description of the suppression of strange particle production from nonstrange systems which gives rise to the low observed K/π ratios. It is not clear whether there is some inherent $SU(3)$ symmetry breaking effect which suppresses strange particle final states or whether the large pion excess can be completely explained by kinematic factors such as phase space.

For example, a comparatively large excess of pions over kaons in multiparticle hadron production is obtained from the simple assumption that all mesons are produced as quark-antiquark pairs in all possible states in a completely $SU(6)$ symmetric way with no symmetry breaking. The statistical spin factor favors vector mesons by a factor of 3:1 over pseudoscalars and a strong effective $SU(3)$ symmetry breaking sets in because the ρ and ω happen to be below the $K\bar{K}$ threshold. A large excess of pions is obtained from ρ and ω decays because the kaon pair decay channels are closed by mass considerations and the kaons which would balance the pions in the $SU(3)$ symmetry limit are completely absent.

Decays of resonances and couplings of Regge trajectories to hadrons have been described successfully by assuming that $SU(3)$ holds exactly for the coupling constants and that all symmetry breaking arises from kinematic factors resulting from mass differences.² However the evidence is not conclusive. The ambiguities are crucial for interpretations of the strengths of the strange and charmed particle production reactions (2.1a) and (2.1b). If all the symmetry breaking is due to kinematic factors the N^* in the reactions (2.1) may have a sufficiently high mass to make all kinematic breaking effects small in quasi-two-body decays. In that case there should be no additional symmetry breaking effects and the reactions (2.1a) and (2.1b) should approach the $SU(3)$ and $SU(4)$ limits at high masses. On the other hand, the strange particle production by the mechanism (2.1a) may be suppressed by an order of magnitude by inherent symmetry breaking which persists at high energies and there could be an additional order of magnitude in the suppression of charmed pair production³ by the reaction (2.1b). This view suggests that charmed pair production by the reaction (2.1b) should indeed be very small.

Recent data on strange particle production by neutrinos⁴ seem to indicate that it is mainly the associated production by the reaction (2.1a) rather than the single production by the reaction (2.2a) and that the neutrino production looks very similar to the strange particle production by the electromagnetic current in deep inelastic electron and photoproduction experiments.

If these results for strange particle production are relevant to charmed particle production some of the dimuon events observed in neutrino experiments might result from associated production of

pairs of new particles by the reaction (2.1b) rather than by the single production reaction (2.2b). If these reactions are associated production analogous to strange particle production they should be similar to the production of the same type of particle in hadron reactions. There should then be evidence of such muon production in hadron experiments. Direct comparison of weak and strong muon production would test this model, but is somewhat difficult. The quantity quoted in hadron experiments is the μ/π ratio whereas weak interaction experiments quote the percentage of events in which a muon is observed. Numbers floating around are of the order of 1 muon event per hundred events and a μ/π ratio in hadron events of the order of 10^{-4} . This difference of two orders of magnitude might be accounted for by the multiplicity factor to change the μ/π ratio to the fraction of events containing muons and by possible kinematic factors arising because of differences in kinematic regions observed in the different experiments. Back of the envelope type calculations thus indicate that the kind of associated production observed in hadron experiments could account for a significant part of the dimuon events observed in the neutrino experiments.

The purpose of the above discussion in the present context is to underline the implications in many areas of our ignorance of a very basic question concerning strange particles, namely whether there is a basic SU(3) symmetry breaking which discriminates against the production of strange particles or whether all the observed suppression is explainable by simple kinematics. The conclusion is that strange particle production needs further investigation, both theoretical and experimental, and that studies with hyperon beams may give us some additional information.

III. STRANGENESS EFFECTS IN HADRON TOTAL CROSS SECTIONS

The very precise experimental data ⁵ now available on pion, kaon and nucleon total cross sections give us some information about the difference between the interactions of strange and nonstrange particles with matter. Careful examination of the data show that this difference is very interesting but also very puzzling and not really understood. ⁶ Figure 3.1 shows the conventional plot of total cross sections versus laboratory momentum on a logarithmic scale. Figure 3.2 shows the systematics in a more interesting plot of the same data with a square root scale rather than a logarithmic scale for P_{lab} and with the total cross section multiplied by $\sqrt{P_{lab}}$. This is equivalent at these high energies to a plot against center-of-mass momentum of the imaginary part of the forward amplitude obtained from the total cross section by the optical theorem. Theoretical

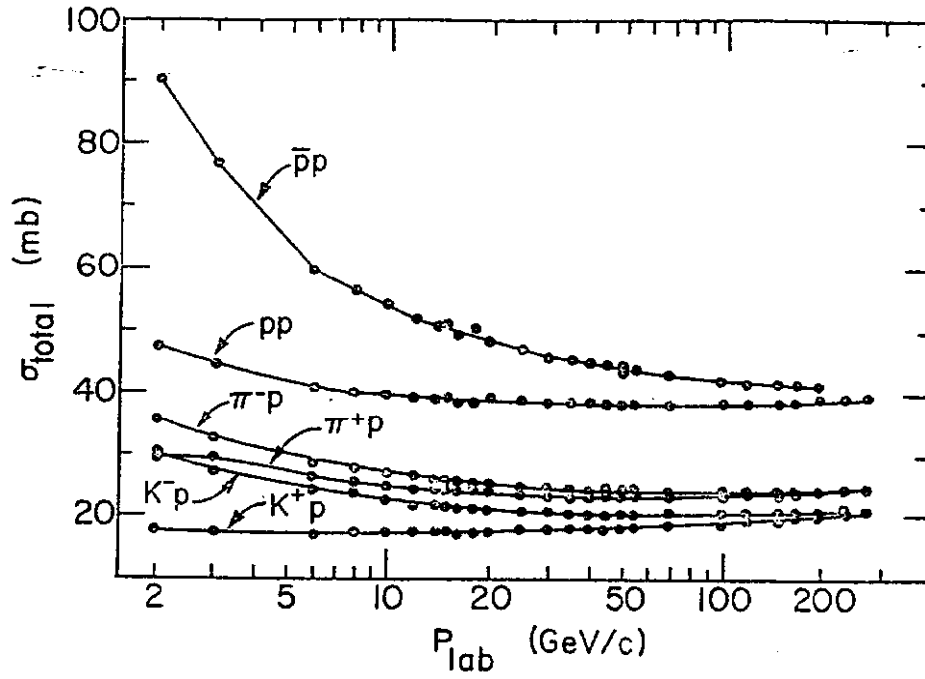


Fig. 3.1. Total Cross Sections vs. P_{lab} .

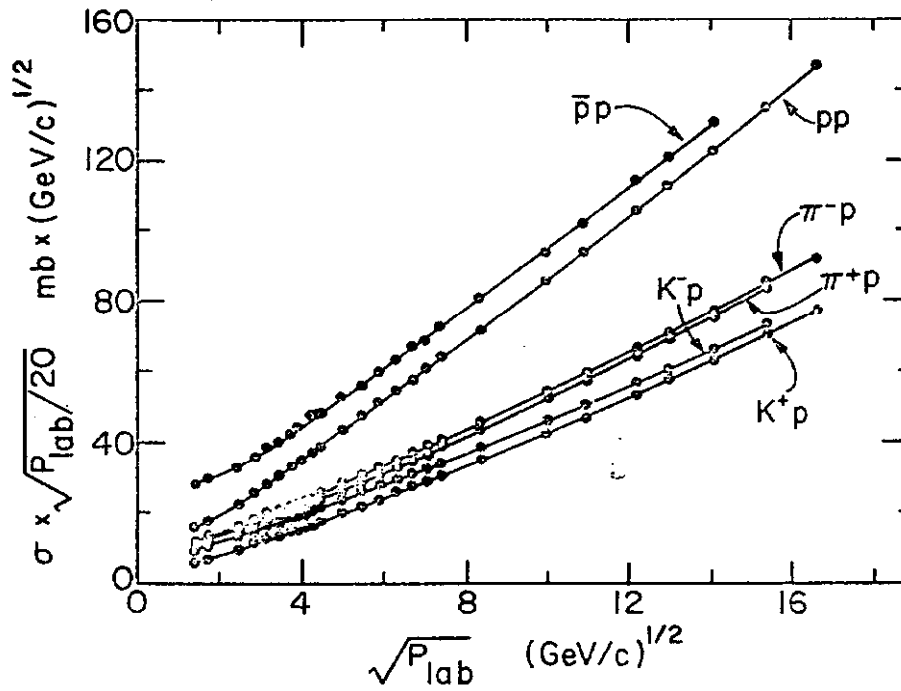


Fig. 3.2. $\sigma_{\text{tot}} \sqrt{P/20}$ vs. \sqrt{P} .

reasons why the curve of 3.2 is so much simpler than the standard plot of Fig. 3.1 follow from a two-component description of the cross sections with a Regge component varying as $s^{-1/2}$ and a pomeron component varying slowly as a function of energy. A more detailed discussion is given elsewhere.⁷ For our purposes this particular plot shows very clearly that there is a difference between strange and nonstrange particles and that there are puzzles not explained by the quark model. These are shown very strikingly in Fig. 3.3 which plots exactly the same quantities as those in Fig. 3.2 with the nucleon-nucleon and nucleon-antinucleon cross sections multiplied by a factor $2/3$. The six quantities plotted are all predicted to be equal asymptotically by the quark model if the pomeron component is an SU(3) singlet coupled equally to pions and kaons and coupled to mesons and baryons by simple quark counting prescriptions. Figure 3.3 shows that these cross sections are indeed all equal at the 20% level. However, beyond this approximation of "seen one hadron, seen them all" the difference between the πp and the pp cross sections is seen to be strangely similar to the difference between the πp and Kp cross sections. The difference between mesons and baryons seems to be similar to the difference between nonstrange and strange mesons. This is shown more precisely by examining linear combinations of cross sections which have no Regge component

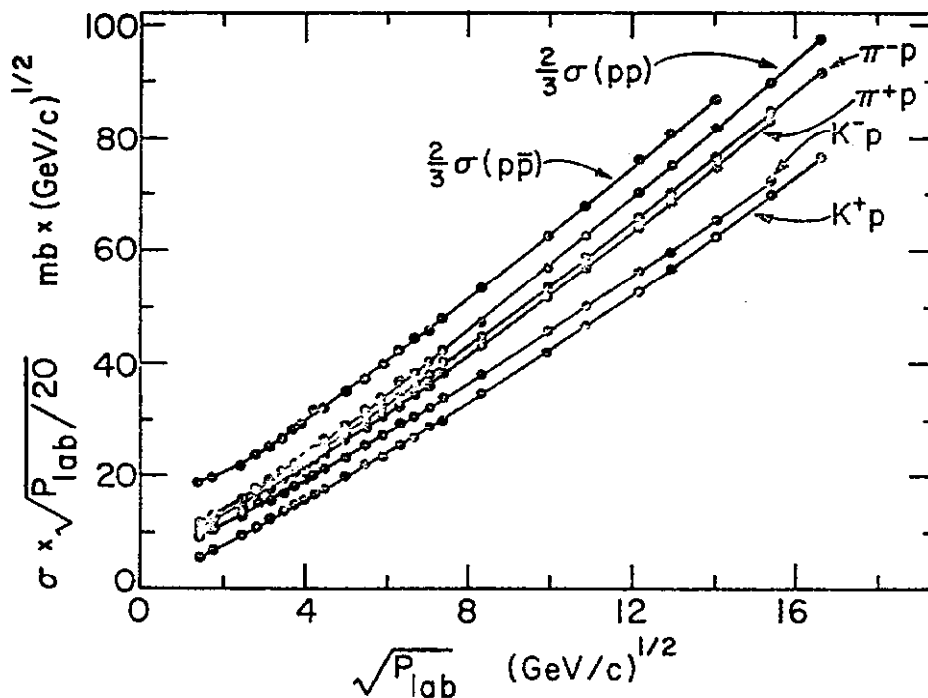


Fig. 3.3. $\sigma_{\text{tot}} \sqrt{P/20}$ vs. \sqrt{P} . Nucleon cross sections multiplied by $2/3$.

and are therefore pure pomeron in the two-component description. The K^+p and pp channels are exotic and have no contribution from the leading Regge exchanges under the common assumption of exchange degeneracy. The following linear combinations of meson-nucleon cross sections are constructed to cancel the contributions of the leading Regge trajectories.

$$\sigma(\phi p) = \sigma(K^+p) + \sigma(K^-p) - \sigma(\pi^-p) \quad (3.1a)$$

$$\Delta(\pi K) = \sigma(\pi^-p) - \sigma(K^-p). \quad (3.1b)$$

Figure 3.4 shows these two quantities on the conventional plot of cross section versus the P_{lab} on a log scale.

$\sigma(\phi p)$ as defined by Eq. (3.1a) is the quark model expression for $\sigma(\phi p)$; i. e., the cross section for the scattering of a strange quark-antiquark pair on a proton. The very simple energy behavior of this quantity as seen in Fig. 3.4 is striking. It shows a monotonic rise beginning already at 2 GeV/c. That total cross sections rise at high energies was first noted in the Serpukhov data from 20-50 GeV/c, but the older data at lower energies already show this rising behavior in $\sigma(\phi p)$. If anyone had suggested something particularly fundamental about this cross section for strange quarks on

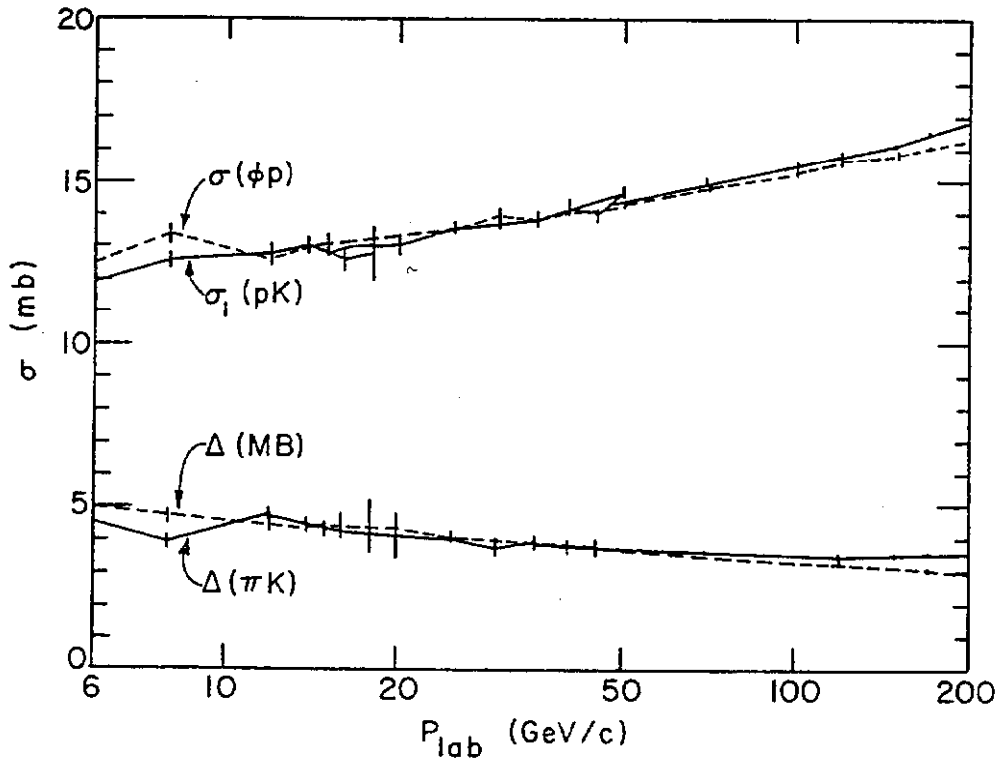


Fig. 3.4. Plots of Eqs. (3.1) and (3.2).

a nucleon before the Serpukhov data were available and concluded that its rising cross section indicated that all cross sections would eventually rise he would naturally have been disregarded as crazy. But now that the whole picture up to 200 GeV/c is available we may conclude that there is indeed something simpler and more fundamental about the cross sections for strange quarks on a proton target. Understanding this simpler behavior may help us to understand the more complicated energy behavior of the other cross sections.

The quantity $\Delta(\text{MB})$ defined by Eq. (3.2b) represents the difference in the scattering of a strange particle and a nonstrange particle on a proton target. In the quark model this is the difference between the scattering of a strange quark and a nonstrange quark on a proton target after the leading Regge contributions have been removed. This difference between strange and nonstrange also has a very simple energy behavior, decreasing constantly and very slowly (less than a factor of 2 over a range P_{lab} of two orders of magnitude). So far there is no good explanation for why strange and nonstrange mesons behave differently in just this way.

Since the two quantities (3.1) have no contribution from the leading Regge trajectories they represent something loosely called the pomeron. However their energy behaviors are different from one another and also from that of the quantities $\sigma(K^+p)$ and $\sigma(pp)$ which should also be "pure pomeron." However the following linear combinations of $\sigma(K^+p)$ and $\sigma(pp)$ have exactly the same energy behavior as the meson-baryon linear combinations (3.1).

$$\sigma_1(pK) = \frac{3}{2}\sigma(K^+p) - \frac{1}{3}\sigma(pp) \quad (3.2a)$$

$$\Delta(\text{MB}) = \frac{1}{3}\sigma(pp) - \frac{1}{2}\sigma(K^+p) \quad (3.2b)$$

These quantities are also plotted in Fig. 3.4.

The equality of the quantities (3.2) and the corresponding quantities (3.1) suggest that the pomeron, defined as what is left in the total cross sections after the leading Regge contributions are removed by the standard prescription, consists of two components, one rising slowly with energy and the other decreasing slowly. The coefficients in Eq. (3.2) were not picked arbitrarily but were chosen by a particular model. In this model the rising component of the total cross section is assumed to satisfy the standard quark model recipe exactly.

$$\sigma_R(Kp) = \sigma_R(\pi p) = \frac{2}{3}\sigma_R(pp) = \frac{2}{3}\sigma_R(Yp) = \frac{2}{3}\sigma_R(\Xi p), \quad (3.3a)$$

where Y denotes a Λ or Σ hyperon. The falling component has been assumed to satisfy the following relation

$$\sigma_F(Kp) = \frac{1}{2}\sigma_F(\pi p) = \frac{2}{9}\sigma_F(pp) = \frac{1}{3}\sigma_F(Yp) = \frac{2}{3}\sigma_F(\Xi p). \quad (3.3b)$$

This particular behavior is suggested by a model in which the correction to a simple quark-counting recipe comes from a double-exchange diagram involving a pomeron and an f coupled to the incident particle. One example of such a diagram is shown in Fig. 3.5. Such a diagram might account for the decreasing component.

We thus see unresolved problems in the total cross-section data associated with the questions of what is the difference between strange and nonstrange particles and what is the nature of the pomeron. Note that Eq. (3.1b) defines the difference between the scattering of a nonstrange quark and a strange quark while Eq. (3.2b) can be interpreted as the difference between the scattering of a quark in a baryon and a quark in a meson. The fact that the strange-nonstrange difference and the meson-baryon difference are equal and have the same energy behavior over such a wide range is a puzzle which may be explained by a diagram of the form of Fig. 3.5 but may also indicate something deeper.

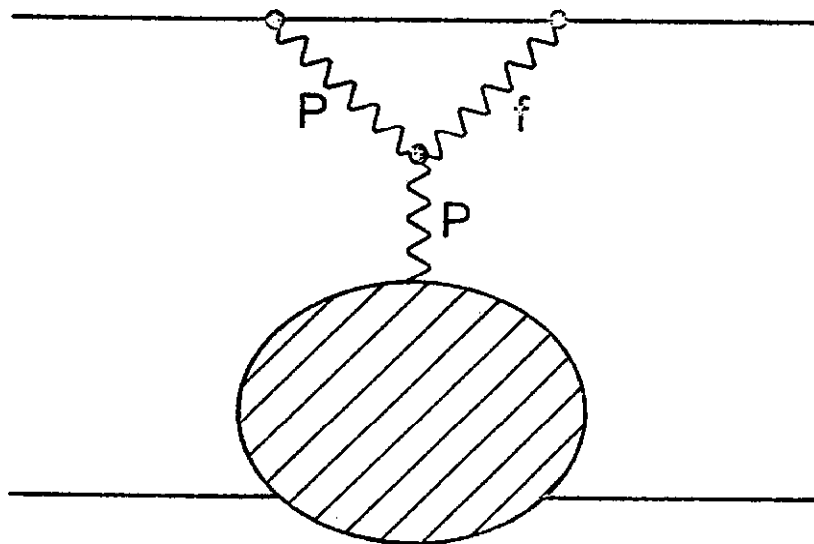


Fig. 3.5. Triple Regge Diagram

Measurements of hyperon-nucleon cross sections may give further clues to the nature of the strange-nonstrange difference. In particular there is a difference between the predictions of the simple quark model which attributes the strange-nonstrange difference to the difference in the scattering of strange and nonstrange quarks and the two-component pomeron model which attributes the strange-nonstrange difference to a contribution having the form of Eq. (3.3b). This difference is expressed in the predictions for the hyperon-nucleon total cross section.

$$\sigma_{QM}(\Sigma p) = \sigma_{QM}(\Lambda p) = \sigma(pp) - [\sigma(\pi^- p) - \sigma(K^- p)] \quad (3.4a)$$

$$\sigma_{2P}(\Sigma p) = \sigma_{2P}(\Lambda p) = \sigma(pp) - \frac{3}{2}[\sigma(\pi^- p) - \sigma(K^- p)] \quad (3.4b)$$

where the subscript QM denotes the simple quark model prediction and the subscript 2P denotes the prediction from the two-component pomeron model given by Eq. (3.3). Present data do not distinguish between these two predictions. Typical values at about 20 GeV/c are 35 mb for the prediction (3.4a), 33 mb for the prediction (3.4b) and 34 ± 1 mb for the CERN experimental data. Better data should give a significant test of the difference in the near future. Larger effects are expected for the Ξ -nucleon total cross sections where the analogous predictions are given by

$$\sigma_{QM}(\Xi p) = \sigma(pp) - 2[\sigma(\pi^- p) - \sigma(K^- p)] \quad (3.5a)$$

$$\sigma_{2P}(\Xi p) = \sigma(pp) - 3[\sigma(\pi^- p) - \sigma(K^- p)]. \quad (3.5b)$$

The two-component pomeron also gives the following direct predictions for hyperon-nucleon cross sections in terms of the K^+p and pp cross sections

$$\sigma_{2P}(\Sigma p) = \sigma_{2P}(\Lambda p) = \frac{3}{4}\sigma(K^+ p) + \frac{1}{2}\sigma(pp) \quad (3.6a)$$

$$\sigma_{2P}(\Xi p) = \frac{3}{2}\sigma(K^+ p). \quad (3.6b)$$

IV. SPIN-ISOSPIN STRUCTURE IN HYPERONS

Hyperons have a richer isospin structure than nucleons with two hyperon states Λ and Σ having identical values of all quantum numbers except isospin. Thus studies of the Λ - Σ difference give information about baryon structure not available from nucleons. One example is the Λ - Σ mass difference which is not understood in any simple model.

The Λ - Σ isospin doublet is very different from the superficially similar meson isospin doublet ω - ρ which occupies the corresponding position in the SU(3) octet. The ρ and ω are G-parity eigenstates described in the quark model as two-body systems with identical spin couplings differing only in the relative phases of components of the wave function having different isospin quantum numbers. Charge conjugation uniquely determines the SU(3) couplings of three meson octets to be either pure D-type or pure F-type. But the ω is a mixed singlet-octet state with a mixing angle.

The baryons are in a pure octet and have no mixing angle. But the SU(3) coupling to the baryon octet has no restriction from charge conjugation and the (D/F) ratio can be determined only by going beyond SU(3). In the quark model the Λ and Σ^0 are three-body systems having exactly the same quark content and differing only in the spin couplings. Spin is tied to isospin in the quark model by SU(6) which requires total symmetry in spin and isospin.

Both the Λ and Σ hyperons consist of two nonstrange quarks and one strange quark. In the Λ the two nonstrange quarks are coupled to isospin zero. They therefore have spin zero by the symmetry requirement of SU(6) and do not contribute to the total spin. The hyperon spin is thus exactly equal to the spin of the strange quark. In the Σ the nonstrange quarks are coupled to isospin one and therefore also to spin one. This spin one must be antiparallel to the spin of the strange quark to give a total spin of $1/2$. Thus in the Σ the total spin of the hyperon is antiparallel to the spin of the strange quark whereas in the Λ it is parallel. This difference in spin structure of the Λ and Σ has many implications which can be tested experimentally.

One of the great successes and also the great paradoxes of the quark model description of the nucleon has been in the spin-isospin structure. The very successful prediction of $-3/2$ for the ratio of the proton and neutron magnetic moments⁸ is a direct result of the assumed spin-isospin structure. Exactly the same spin-isospin structure is successful in the description of the strong couplings of the nucleon to the vector mesons, namely, that the nonflip coupling of the ω to the nucleon is much greater than the nonflip coupling of the ρ and that the flip coupling of the ρ is much greater than the nonflip coupling.

The manner in which the spin-isospin structure of the nucleon determines many nucleon properties is illustrated by Fig. 4.1 which shows schematically the spin and magnetic moment couplings in the nucleon. SU(6) requires the two identical p quarks in the proton to have parallel spins and therefore the spin of the odd-n quark to be antiparallel to that of the p quarks to give a total spin of $1/2$. However, because the electric charge of the n quark is opposite to that of the p quark antiparallel spin means parallel magnetic moments so that the magnetic moments of the three quarks add up to give a large value.

We thus note a very simple general property of the spin-isospin couplings of the nucleon which applies to all properties obtained by adding up the contributions of the individual quarks. Quantities like the total spin or the total isospin which are vectors either in isospin or ordinary spin space but not in both have contributions of opposite sign from the p and n quarks which tend to cancel one another. Quantities like the magnetic moments which are vectors in both spin and isospin space and quantities like the total quark number which is a scalar in both spin and isospin space add all contributions with the same sign. This is summarized in Table 4.1. These qualitative considerations which hold equally for strong, electromagnetic and weak couplings suggest a common origin in the

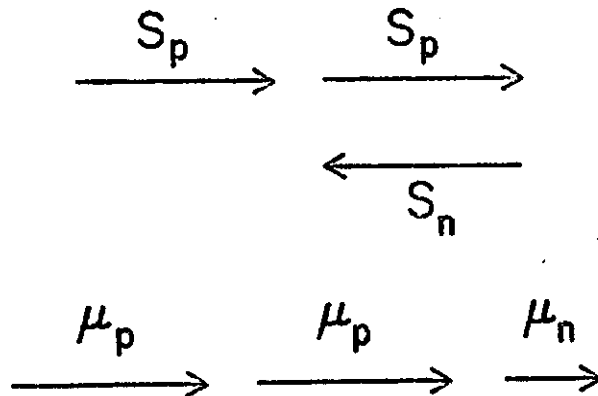


Fig. 4.1. Spin and Magnetic Moment Couplings in the Nucleon.

TABLE 4.1. Spin-Isospin properties of nucleons

	Isospin Scalar	Isospin Vector
Spin Scalar	Large (3 x quark) $g_{\omega NN}$ (nonflip), baryon number	Small (same as quark) $g_{\rho NN}$ (nonflip), electric charge, G_V
Spin Vector	Small (same as quark) $g_{\omega NN}$ (flip), spin	Large (3 x quark) $g_{\rho NN}$ (flip), μ_p, μ_n, G_A

structure of the nucleon rather than in any one particular interaction. However, a paradox arises on the quantitative level because the prediction of the magnetic moment ratio is in very good agreement with experiment whereas the prediction for the value of G_A/G_V is not so good.

$$\mu_p/\mu_n = -3/2 \quad (\text{Good}) \quad (4.1a)$$

$$G_A/G_V = 5/3 \quad (\text{Bad}). \quad (4.1b)$$

This difference might be due to relativistic corrections to the spin-isospin structure. Experiments on the spin-isospin structure of hyperons might shed additional light on this question.

The magnetic moments of hyperons are determined uniquely in the SU(6) limit by the magnetic moment of the nucleon. Ambiguities arise because of SU(6) breaking in the mass differences. In the symmetry limit the quark magnetic moments are the same in hyperons as in nucleons, but the Bohr magneton of a particle depends upon its mass. This raises two questions regarding the quark magnetons.

1. How does the strange quark magneton differ from the non-strange quark magneton?

2. Does the magneton of a nonstrange quark in a hyperon differ from the magneton of a nonstrange quark in a nucleon?

Both of these questions could be answered by precise measurements of hyperon magnetic moments. They would shed light on the question of the "effective mass" of a quark in a hadron.

The quark model predictions for hyperon magnetic moments can be generalized to include the above mass effects. Let a parameter δ describe the symmetry breaking difference between the magnetic moments of strange and nonstrange quarks.

$$\delta \equiv \mu_{n\text{-quark}} - \mu_{\lambda\text{-quark}} \quad (4.2)$$

Let g_Y/g_N be the ratio of the magnetic moment of a quark in hyperon Y to the magnetic moment of the same quark in a nucleon. Then the quark model with symmetry breaking predicts

$$\mu_n = -\frac{2}{3}\mu_p \quad (4.3a)$$

$$\mu_{\Sigma^+} = (\mu_p + \frac{1}{3}\delta)(g_{\Sigma}/g_N) \quad (4.3b)$$

$$\mu_{\Sigma^-} = (-\frac{\mu_p}{3} + \frac{1}{3}\delta)(g_{\Sigma}/g_N) \quad (4.3c)$$

$$\mu_{\Sigma^0} = (\frac{\mu_p}{3} + \frac{1}{3}\delta)(g_{\Sigma}/g_N) \quad (4.3d)$$

$$\mu_{\Lambda} = (-\frac{1}{3}\mu_p - \delta)(g_{\Lambda}/g_N) \quad (4.3e)$$

$$\mu_{\Xi^0} = (-\frac{2\mu_p}{3} + \frac{4}{3}\delta)(g_{\Xi}/g_N) \quad (4.3f)$$

$$\mu_{\Xi^-} = (-\frac{\mu_p}{3} + \frac{4}{3}\delta)(g_{\Xi}/g_N). \quad (4.3g)$$

Spin-isospin effects in the Λ and Σ are also measured in production and decay processes involving a nucleon-hyperon transition. The SU(6) or quark model description of this transition has the same very striking features for all processes, including both weak interactions and strong interactions with K or K^* exchange. The strangeness change is described by a single quark operator acting between a nonstrange quark in a proton and a strange quark in the hyperon. The other two nonstrange quarks are spectators whose spins are unchanged and remain coupled to spin zero for Λ transitions and spin one for Σ transitions. Thus in the Λ , where the strange quark carries the spin and helicity of the baryon, the spin or helicity of the Λ is flipped by simply flipping the spin of the strange quark. In the Σ where the strange quark spin is mainly antiparallel to the total spin of the hyperon, spin or helicity flip is a complicated operation and not easily achieved by single-quark operators. Such quark-spin arguments predict that Λ production is

always favored over Σ and by very large factors in spin-flip transitions. In SU(3) language the spin couplings determine the D/F ratio to suppress the Σ relative to the Λ . Experimental results have generally not borne out these predictions and leave a puzzle of why spin-isospin predictions seem to work well in some areas and not in others.⁸

V. DETAILED ANALYSIS OF STRANGENESS-EXCHANGE COUPLINGS

Two single-quark operators describe nucleon-hyperon transitions. One transforms like a vector under quark-spin rotations, the other like a scalar. The scalar operator is a V-spin generator whose squared matrix elements between the proton and the Λ , Σ^0 and Y^{*0} (1385) states are in the ratio 3:1:0. The vector operator is an SU(6) generator and its squared matrix element between the proton and the Λ , Σ^0 and Y^{*0} (1385) states are in the ratio 27:1:8. The universal character of these predictions for all strangeness changing processes suggests a comprehensive analysis of all nucleon-hyperon transitions and a comparison with the simpler ρ - ω case.

Relations between ρ and ω production agree very well with experiment.⁹ Relations between ρ and ω exchange contributions to meson-baryon total cross sections disagree by small factors¹⁰ with experiment. Relations between Λ and Σ production are often off by very large factors.¹¹ Finite energy sum rules have been used¹² to relate the discrepancy in ρ and ω exchange to the discrepancy in Λ and Σ production.

Recent experiments on proton-antiproton annihilation¹³ into strange meson pairs provides a new kind of comparison between Λ and Σ couplings. The data show a large excess of charged final states over neutral states in quasi-two-body channels. In an s-channel picture this implies a very strong interference between isoscalar and isovector amplitudes. In a t-channel picture this implies that Λ exchange dominates over Σ exchange as predicted by quark models or SU(6)_W symmetry. This qualitative agreement contrasts with the disagreement observed in production of hyperons by strange meson exchange. Further examination of these processes could check whether the discrepancy is due to inadequacies in the spin-isospin structure assumed for the hyperons or to the mechanisms assumed for the particular reactions.

The annihilation reaction differs in several important aspects from the hyperon production reactions. In annihilation the strange bosons are on the mass shell and the hyperon is exchanged whereas in the hyperon production process the hyperon is on the mass shell

and the boson is exchanged. In the annihilation process the same hyperon-nucleon-boson vertex appears twice and any suppression of Σ to Λ appears squared. Bosons are directly observed and identified in annihilation and their polarizations can be measured. This contrasts with the hyperon production reaction where the boson is directly observed and considerable model-dependent analysis is required to separate K and K^* exchanges and determine the helicity of an exchanged K^* . If the annihilation process is dominated by Λ and Σ exchanges the different spin couplings can be cleanly separated by looking at all the different quasi-two-body final states involving kaons and K^* vector mesons and measuring the K^* polarization.

Table 5.1 gives the $SU(6)_W$ or quark model predictions for the ratios of the couplings of the Λ , Σ and $Y^*(1385)$ hyperons to a proton and strange boson. The two sets of predictions correspond to the two different spin couplings, scalar and vector discussed above. The scalar spin-independent coupling applies to longitudinally polarized vector bosons. The vector coupling applies to pseudoscalar and transversely polarized vector bosons.

Table 5.2 gives predictions for the ratio of the cross sections for production of charged pairs to neutral pairs calculated from Table 5.1 by noting that all neutral exchanges contribute to the production of charged pairs and all charged exchanges contribute to the production of neutral pairs. The three cases correspond to different spin states at the two vertices. Y^* exchange is allowed when both vertices are spin dependent. It is not clear whether the Y^* exchange contribution should be added directly to the octet exchange or be suppressed in view of the experimental observation that decuplet exchange is suppressed relative to octet exchange. If Y^* exchange is not included a very large ratio of 196 is predicted between charged and neutral kaon pair production. If the Y^* contribution is included the ratio drops to 4. This suggests that any neutral pairs observed are produced by Y^* exchange while the charged pairs are produced by octet exchange.

TABLE 5.1. Values of $g_{KY\bar{P}}$ from $SU(6)_W$ or quark model

Y	Λ	Σ^0	Y^{*0}	Σ^+	Y^{*+}
$g_{KY\bar{P}}$ (spin scalar)	$3\sqrt{3}$	3	0	$3\sqrt{2}$	0
$g_{KY\bar{P}}$ (spin vector)	$3\sqrt{3}$	-1	$-2\sqrt{2}$	-2	-4

TABLE 5.2. Predictions for charged and neutral kaon pair production in $p\bar{p}$ annihilation

Kaon state	Contributions to amplitude from exchange of				$\frac{\sigma(K^\pm)}{\sigma(K^0)}$
	$\Lambda + \Sigma^0$	Y^{*0}	Σ^+	Y^{*+}	
$K_L^* \bar{K}_L^*$	36	0	18	0	4
$K\bar{K}, K_T^* \bar{K}_T^*$	28	8	2	16	196 - No Y^*
$K\bar{K}_T^*, K_T^* \bar{K}$					4 - Coherent Y^*
$K_T^* \bar{K}$	24	0	-6	0	16

The subscripts L and T denote longitudinal and transverse polarization respectively in the Jackson frame.

Experimental results indicate a large charge excess for the $K\bar{K}$ final state. The cross section for charged meson production is found to behave like Λ exchange whereas the neutral production decreases faster with energy and would seem to be due to another exchange. This is consistent with the picture in which the ratio of charged to neutral production by Λ and Σ exchanges is 196 and therefore any neutrals observed with a cross section greater than 1% of the charged cross section must be due to another exchange mechanism. Further experimental data with polarization measurements on K^* states in the Jackson frame would be of interest.

The nucleon-hyperon transition can also be tested in other reactions. In all cases two of the particles appearing in the three-point vertex function are directly observed and the third is an exchanged particle or trajectory whose identity must be guessed. In hyperon production by meson exchange, the identity of the exchanged meson is unclear. In annihilation or the line-reversed process of backward kaon scattering or K^* production, the identity of the exchanged hyperon is unclear. Hyperon exchange can also be studied in backward scattering reactions with strangeness exchange with incident pions or kaons producing Λ 's and Σ 's or Ξ 's, respectively. In all these cases the production of charged baryons by incident charged mesons should dominate over neutral baryon production if the prediction of Λ exchange dominance is valid. The third case

where the nucleon is exchanged is in hyperon production by backward kaon-nucleon reactions. If nucleon exchange dominates these processes Λ production is predicted to be stronger than $\bar{\Sigma}$ production.

Since Λ dominance has now been observed experimentally in the annihilation reaction, while being in strong disagreement with the data on meson-baryon strangeness exchange reactions, it would be interesting to examine all transitions where the nucleon-hyperon strangeness-changing coupling occurs including weak as well as strong interactions to see if there is any systematic pattern.

VI. DRINK NONLEP TONIC

Nonlep tonic is intoxicating stuff for theoretical physicists. When a theorist takes a little nonlep tonic he suddenly experiences a feeling of great illumination. He sees visions in which everything suddenly becomes clear. As he takes a bit more everything seems to fit into place and he becomes very happy and excited. But more nonlep tonic suddenly makes the world become fuzzier and fuzzier. Finally the clarity of the vision disappears and all that remains is a headache and a hangover.

Let us take a little nonlep tonic and look for inspiration in the appropriate place, namely the Rosenfeld tables. We find the surprising experimental fact that the three nonleptonic decay modes of the Σ all have equal decay rates, even though $\Sigma^+ \rightarrow n\pi^+$ is believed to be pure p-wave, the $\Sigma^- \rightarrow n\pi^-$ is believed to be pure s-wave and $\Sigma^+ \rightarrow p\pi^0$ must be an exactly equal mixture of s wave and p wave in order to give the observed asymmetry parameter $a = -1$. This equality of s- and p-wave decay amplitudes cannot possibly be an accident. Treatments of nonleptonic decays which consider s waves and p waves on a different footing with different diagrams and different parameters must be complete nonsense. It is like describing hadron masses without isospin and obtaining two mass formulas one for charged particles which fits the proton very well and another for neutral particles which fits the neutron very well, but no indication of why the proton and neutron masses are so nearly equal. There must be a way to treat nonleptonic hyperon decays and include this s-p symmetry which is clearly present in the experimental data.

After taking a bit of nonlep tonic it becomes obvious that s and p waves can be treated together by using helicity amplitudes which are equal mixtures of s and p waves. Helicity is a natural description for weak interactions because only left-handed quarks are coupled. We assume the Levin-Frankfurt "single-quark operator" approximation in which the weak interaction is described by a spurion which changes a left-handed strange quark in the hyperon into a left-handed nonstrange quark, while the other two quarks are spectators for the weak interaction.

Our next dose of nonlep tonic reveals that we predict that the Λ and Σ decays should have the opposite sign for the asymmetry parameter, in agreement with experiment, and we become very excited. This is because the spin couplings of the active strange quarks to the other quarks in a hyperon is such that a left-handed strange quark is found in a left-handed Λ but in a right-handed Σ ! The spin-isospin structure of the baryon-56 requires a pair of nonstrange quarks with isospin zero to have ordinary spin zero and a pair with isospin one to have ordinary spin one. Thus in the case of two nonstrange quarks with isospin zero as in the Λ , the nonstrange diquark has spin zero and the remaining third quark carries the whole spin of the baryon. For the case where the diquark has isospin one as in the case of the Σ , the spin of the third quark must be antiparallel to that of the diquark to give a total spin of $1/2$. Thus the spin of the third quark is antiparallel to the spin of the baryon.

With a little more nonlep tonic we look at the individual Σ decay modes. In the $\Sigma^+ \rightarrow p\pi^0$ decay the two spectator quarks in the final proton are both p quarks and have isospin one and spin one. Their spin must therefore be antiparallel to the left-handed active quark to give a total spin of $1/2$. Thus the $\Sigma^+ \rightarrow p\pi^0$ decay produces a proton which is purely right handed and has an equal mixture of s and p waves and full asymmetry. For the case of $\Sigma^+ \rightarrow n\pi^+$ and $\Sigma^- \rightarrow n\pi^-$ decays the two spectator quarks in the final neutron which did not participate in the weak interaction are a p and an n which have $I_z = 0$ and are linear combinations of isospin zero and isospin one. Thus there are both left-handed and right-handed components in the outgoing neutron. However the isospin couplings show that the relative phase of the $I = 0$ and $I = 1$ components is opposite in the Σ^+ and Σ^- decays. Therefore the relative phase of the left-handed and right-handed helicity states will also be opposite. If their magnitudes are equal they produce eigenstates of the orbital angular momentum and one will be pure s wave and the other pure p wave. Miraculous!

At this point the nonlep tonic has reached its peak of elucidation and things begin to get fuzzy. What is a left-handed hyperon? At rest its helicity is undefined. For the infinite momentum frame we can either choose $p_z = +\infty$ or $p_z = -\infty$. A given hyperon state is right handed in one frame and left handed in the other, but it is the same hyperon. We cannot say that it decays in one frame and does not decay in the other. Furthermore, the statement that the spins of the strange quark and the nonstrange diquark in a Σ are antiparallel is not exact. When the correct couplings are put in they are antiparallel $2/3$ of the time and parallel $1/3$ of the time. But the asymmetry of the $\Sigma^+ \rightarrow p\pi^0$ decay is 100% and not $2/3$. In the Λ decay the helicity argument is exact because the nonstrange quarks have spin zero. But the Λ asymmetry parameter is about $2/3$ and not 100%.

As we attempt to push further everything only becomes more and more confused. We end up with a headache and a hangover, but a feeling that there is still something in the data, a hidden symmetry which we don't understand.

Much theoretical work has gone into attempts to explain the empirical fact that the $\Delta I = 1/2$ rule works for nonleptonic decays. Perhaps some effort should be put into explaining the empirical equality of the s- and p-wave amplitudes.

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